

Experiment 5

Capacitors in DC Circuits

Preparation

Prepare for this week's quiz by reviewing past material and reading about capacitors.

Principles

A capacitor consists of two conductors separated by an insulator and is used in a circuit to store charge. If a **voltage**, V_o , is applied across a capacitor of **capacitance** C , it will acquire a **charge** $Q_o = CV_o$, and it is said to be charged. The equation for the charging capacitor is:

$$V_C = V_o (1 - e^{-t/RC}).$$

At $t = 0$, $e^{-t/RC} = 1$ and $V_C = 0$. As t increases $e^{-t/RC}$ decreases. Eventually this term gets close to zero and V_C approaches V_o .

If a resistor is then connected across the capacitor and the voltage source is disconnected, the amount of charge held by the capacitor will drop exponentially and the capacitor is said to be discharging. The voltage will drop as well. The equation for the voltage across a discharging capacitor is:

$$V_C = V_o e^{-t/RC}.$$

The product, RC , of the total resistance, R , and the capacitance, C , is called τ , the **time constant**, or **relaxation time** of the circuit. The units of RC are seconds. If the capacitor has charged for an amount of time equal to RC , the voltage across it will equal 63% of V_o . If the capacitor is fully charged and then allowed to discharge, the voltage across it will have dropped to 37% of V_o after time RC .

In this experiment you will build the circuit shown in Figure 1. When the switch is closed, the capacitor will charge until the voltage across it, V_C equals the voltage across the power supply. When you disconnect the plug to the power supply it will no longer keep the capacitor charged. Now the capacitor will discharge through the 22 M Ω resistor (R) and through the voltmeter. At any time the voltage across the capacitor will equal the sum of the voltage across the resistor (IR) and the voltage across the voltmeter (V_m):

$$V_C = IR + V_m$$

Also, at any time the current will equal the meter voltage divided by the meter resistance:

$$I = \frac{V_m}{R_m}$$

Substitute the value for I from the second equation into the first:

$$V_c = V_m \left(\frac{R}{R_m} + 1 \right)$$

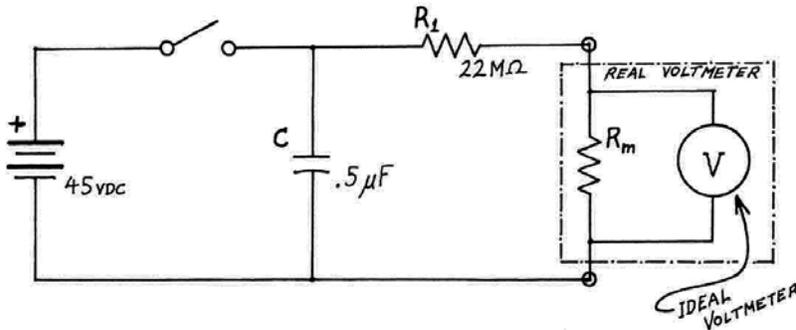


Fig. 1: A capacitor, charged by a battery, is allowed to discharge through two resistors in series: R and R_m (the internal resistance of the meter).

Since the resistances are constant, V_c will differ from V_m by a constant factor. This means that the actual value of the voltage drop across the capacitor can be calculated for any time. When the capacitor is fully charged its voltage will equal that of the power supply, and the voltage across the voltmeter can be measured. These initial conditions can be used to calculate the value of R_m . This value is important because the two resistors are in series and the time constant will equal $C(R + R_m)$.

If a square wave is applied across a capacitor and the frequency is set correctly, the exponential rise and fall of the capacitor voltage can be clearly seen. The circuit for this is shown in Figure 2. Your lab instructor will demonstrate this.

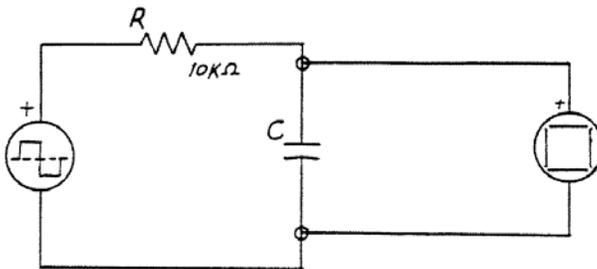


Fig. 2: A series RC circuit driven by an oscillating D.C. (square-wave) voltage. The capacitor voltage is monitored by an oscilloscope.

If a capacitor and resistor are wired in series in an AC circuit, the voltages across the capacitor and the resistor will be 90° out of phase. Also, the voltage across the capacitor will change as the frequency is increased. The circuit for this is shown in figure 3. Your lab instructor will demonstrate this to you. Observe the trace on the 'scope when you answer the questions.

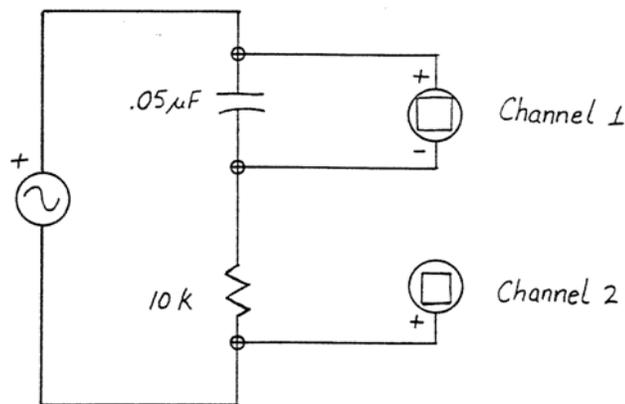


Fig 3

Equipment

- 1 $.1\mu F$ capacitor
- 1 $.5\mu F$ capacitor
- 1 $22M\Omega$ resistor
- 1 multimeter
- 4 2' banana wires, two red, two black
- 1 stopwatch

Procedure

1. Use the voltmeter to measure the output from the DC power supply. Record the voltage. Record the value written on the $.5\mu F$ and the $.1\mu F$ capacitors. Measure and record the resistance of the $22M\Omega$ resistor.
2. Build the circuit shown in Figure 1 using the $0.5\mu F$ capacitor. Plug it in and record V_m . This is the voltage at $t = 0$.
3. Disconnect the red lead from the power supply at $t = 0$. Record V_m at 4 second intervals until you have filled the column or the voltage drops to about 1 volt.

4. Repeat the experiment using the $0.1 \mu\text{F}$ capacitor.
5. Put your equipment away neatly.
6. Observe the circuit shown in Figure 2. Make a drawing of the screen. Note what happens to the trace as the frequency is increased.
7. Observe the circuit shown in Figure 3. Make a drawing of the screen. Notice the phase shift between the capacitor and the resistor. What happens to the capacitor voltage as the frequency is increased?

Analysis

1. Calculate the value for R_m
2. Calculate RC for each capacitor. Remember R is the sum of the resistor and the voltmeter resistances
3. Plot V_m as a function of time for each capacitor. Locate time RC for each graph. Find the voltage at that time. How does this value compare to 37% of the initial meter voltage?